

# Battery Fuel Gauge LSI [Smart LiB Gauge] for 1-Cell Lithium-ion/ Polymer (Li+) with IDD Report

## LC709205F

### Overview

LC709205F is a Fuel Gauge for 1-Cell Lithium-ion/Polymer batteries. It is part of our *Smart LiB Gauge* family of Fuel Gauges which measure the battery RSOC (Relative State Of Charge) using its unique algorithm called **HG-CVR2**. The **HG-CVR2** algorithm provides accurate RSOC information even under unstable conditions (e.g. changes of battery; temperature, loading, aging and self-discharge). An accurate RSOC contributes to the operating time of portable devices. The Fuel Gauge (in other words, Gas Gauge, Battery Monitor or Battery Gauge) feature of **HG-CVR2** algorithm makes LSI highly applicable in various application. The LSI can immediately start battery measurement by setting a few parameters after battery insertion. Learning cycles that make complicated manufacturing process of applications can be avoided.

The LSI also supports battery safety by alarm functions and SOH (State of Health) reporting to the application processor. The operating consumption current is very low 2  $\mu$ A and it is suitable for applications such as wearables and 1 series N parallel batteries.

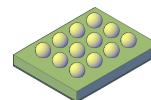
### Features

- **HG-CVR2** Algorithm Technology
  - ◆ Accurate RSOC of Aging Battery
  - ◆ Stable Gauging by Automatic Convergence of Error
  - ◆ Immediate Accurate Gauging after Battery Insertion
  - ◆ Eliminates Learning Cycle
- Low Power Consumption
  - ◆ 2  $\mu$ A Operational Mode Current
- Improvement of the Battery Safety by Alarm Function  
RSOC / Voltage / Current / Temperature
- Battery Lifetime Measurement  
SOH / Cycle Count / Operating Time  
Full Charge Capacity / Remaining Capacity
- Remaining Time Estimation  
Time to Full / Time to Empty
- Three Temperature Inputs
  - ◆ Inputs to sense two NTC Thermistors
  - ◆ Via I<sup>2</sup>C
- Detection of Battery Operating Conditions  
Charging / Discharging
- Detection of Battery Insertion
- I<sup>2</sup>C Interface (supported up to 400 kHz)
- These Devices are Pb-Free, Halogen Free/BFR Free and are RoHS Compliant



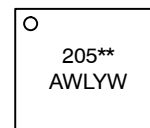
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WLCSP12 1.48x1.91x0.51  
CASE 567XE

### MARKING DIAGRAM



205\*\* = 20501 (LC709205FXE-01TBG)  
A = Assembly Site  
WL = Wafer Lot Number  
YW = Assembly Start Week

### ORDERING INFORMATION

See detailed ordering and shipping information on page 22 of this data sheet.

### Applications

- Wearables / IoT Devices
- Smartphones/PDA Devices
- Digital Cameras
- Portable Game Players
- USB-related Devices

## Application Circuit Example



LC709205F

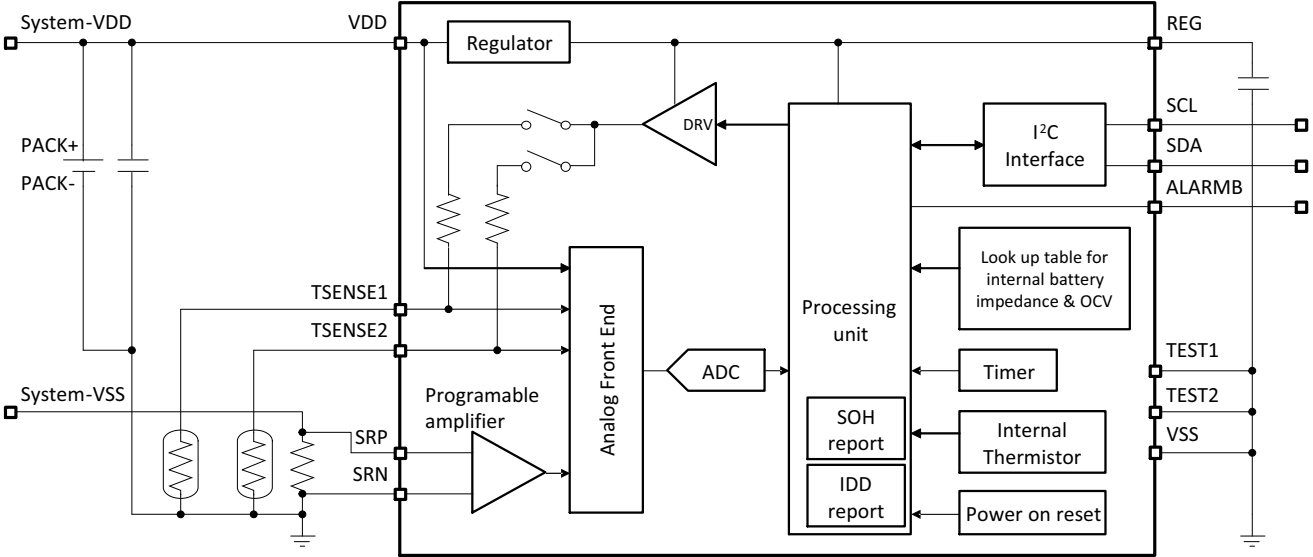
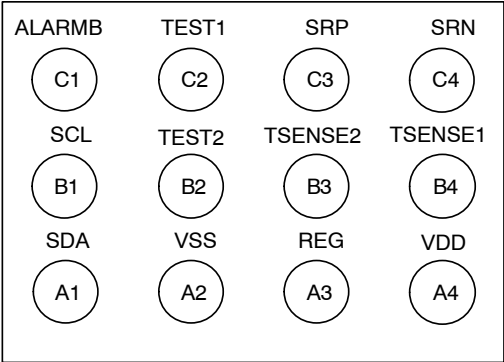


Figure 3. Block Diagram



(Bottom View)

Figure 4. Pin Assignment

**Table 1. PIN FUNCTION**

| WLCSP12 | Name            | I/O | Description                                                                                                                                                      |
|---------|-----------------|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A1      | SDA             | I/O | I <sup>2</sup> C Data pin (open drain). Pull-up must be done externally.                                                                                         |
| B1      | SCL             | I/O | I <sup>2</sup> C Clock pin (open drain). Pull-up must be done externally.                                                                                        |
| C1      | ALARMB          | O   | This pin indicates alarm by low output (open drain). Pull-up must be done externally. Keep this pin OPEN when not in use.                                        |
| A2      | V <sub>SS</sub> | –   | Connect this pin to the battery's negative (–) pin.                                                                                                              |
| B2      | TEST2           | I   | Connect this pin to the battery's negative (–) pin.                                                                                                              |
| C2      | TEST1           | I   | Connect this pin to the battery's negative (–) pin.                                                                                                              |
| A3      | REG             | O   | Regulator output. Connect this pin to the capacitor.                                                                                                             |
| B3      | TSENSE2         | I/O | Sense input and power supply for a thermistor. Connect 10 k $\Omega$ NTC thermistor to measure "Ambient temperature (0x30)". Keep this pin OPEN when not in use. |
| C3      | SRP             | I   | Connect this pin to the sense resistor's positive (+) pin.                                                                                                       |
| A4      | VDD             | –   | Connect this pin to the battery's positive (+) pin.                                                                                                              |
| B4      | TSENSE1         | I/O | Sense input and power supply for a thermistor. Connect 10 k $\Omega$ NTC thermistor to measure "Cell temperature (0x08)". Keep this pin OPEN when not in use.    |
| C4      | SRN             | I   | Connect this pin to the sense resistor's negative (–) pin.                                                                                                       |

**Table 2. ABSOLUTE MAXIMUM RATINGS** (T<sub>A</sub> = 25°C, V<sub>SS</sub> = 0 V)

| Parameter                     | Symbol              | Pin/Remarks                | Conditions                    | V <sub>DD</sub> (V) | Specification |     |      | Unit |
|-------------------------------|---------------------|----------------------------|-------------------------------|---------------------|---------------|-----|------|------|
|                               |                     |                            |                               |                     | Min           | Typ | Max  |      |
| Maximum Supply Voltage        | V <sub>DD</sub> max | VDD                        |                               | –                   | –0.3          | –   | +6.5 | V    |
| Input Voltage                 | V <sub>I</sub> (1)  | ALARMB, SDA, SCL, SRP, SRN |                               | –                   | –0.3          | –   | +6.5 |      |
| Output Voltage                | V <sub>O</sub> (1)  | REG, TSENSE1, TSENSE2      |                               | –                   | –0.3          | –   | +4.6 |      |
| Allowable Power Dissipation   | P <sub>d</sub> max  |                            | T <sub>A</sub> = –40 to +85°C | –                   | –             | –   | 150  | mW   |
| Operating Ambient Temperature | T <sub>aopr</sub>   |                            |                               | –                   | –40           | –   | +85  | °C   |
| Storage Ambient Temperature   | T <sub>stg</sub>    |                            |                               | –                   | –40           | –   | +125 |      |

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

**Table 3. ALLOWABLE OPERATING CONDITIONS** (T<sub>A</sub> = –40 to +85°C, V<sub>SS</sub> = 0 V)

| Parameter                | Symbol              | Pin/Remarks | Conditions | V <sub>DD</sub> (V) | Specification |     |     | Unit |
|--------------------------|---------------------|-------------|------------|---------------------|---------------|-----|-----|------|
|                          |                     |             |            |                     | Min           | Typ | Max |      |
| Operating Supply Voltage | V <sub>DD</sub> (1) | VDD         |            | –                   | 2.5           | –   | 5.0 | V    |

Functional operation above the stresses listed in the Recommended Operating Ranges is not implied. Extended exposure to stresses beyond the Recommended Operating Ranges limits may affect device reliability.

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**Table 4. ELECTRICAL CHARACTERISTICS** ( $T_A = -40$  to  $+85^\circ\text{C}$ ,  $V_{SS} = 0$  V, Typ: 4 V,  $T_A = 25^\circ\text{C}$ )

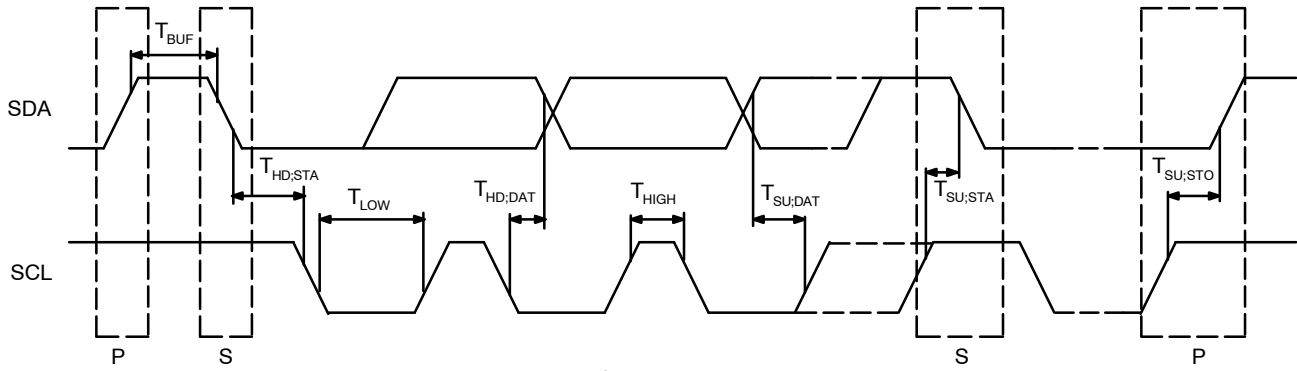
| Parameter                                | Symbol               | Pin/<br>Remarks                  | Conditions                                                                                | Specification       |       |     |       | Unit    |
|------------------------------------------|----------------------|----------------------------------|-------------------------------------------------------------------------------------------|---------------------|-------|-----|-------|---------|
|                                          |                      |                                  |                                                                                           | V <sub>DD</sub> [V] | Min   | Typ | Max   |         |
| LDO                                      |                      |                                  |                                                                                           |                     |       |     |       |         |
| LDO Output Voltage                       | V <sub>REG</sub>     | REG                              |                                                                                           | 2.5 to 5.0          | 2.3   | 2.7 | 3.0   | V       |
| CONSUMPTION CURRENT                      |                      |                                  |                                                                                           |                     |       |     |       |         |
| Operational Mode                         | I <sub>DD</sub> (1)  | VDD                              | Ta = −20°C to +70°C<br>Average current with 0.01C<br>Constant discharge.                  | 2.5 to 5.0          |       | 2   |       | μA      |
| Sleep Mode                               | I <sub>DD</sub> (2)  |                                  | Ta = −20°C to +70°C                                                                       | 2.5 to 5.0          |       | 1.3 |       |         |
| INPUT / OUTPUT                           |                      |                                  |                                                                                           |                     |       |     |       |         |
| High Level Input Voltage                 | V <sub>IH</sub>      | ALARMB,<br>SDA, SCL              |                                                                                           | 2.5 to 5.0          | 1.4   |     | 5.5   | V       |
| Low Level Input Voltage                  | V <sub>IL</sub>      | ALARMB,<br>SDA, SCL              |                                                                                           | 2.5 to 5.0          |       |     | 0.5   |         |
| High Level Input Current                 | I <sub>IH</sub>      | ALARMB,<br>SDA, SCL,<br>SRP, SRN | V <sub>IN</sub> = V <sub>DD</sub><br>(including output transistor<br>off leakage current) | 2.5 to 5.0          |       |     | 1     | μA      |
| Low Level Input Current                  | I <sub>IL</sub>      | ALARMB,<br>SDA, SCL,<br>SRP, SRN | V <sub>IN</sub> = V <sub>SS</sub><br>(including output transistor<br>off leakage current) | 2.5 to 5.0          | −1    |     |       |         |
| Low Level Output Voltage                 | V <sub>OL</sub> (1)  | ALARMB,<br>SDA, SCL              | I <sub>OL</sub> = 3.0 mA                                                                  | 3.3 to 5.0          |       |     | 0.4   | V       |
|                                          | V <sub>OL</sub> (2)  |                                  | I <sub>OL</sub> = 1.3 mA                                                                  | 2.5 to 5.0          |       |     | 0.4   |         |
| Hysteresis Voltage                       | V <sub>HYS</sub>     | ALARMB,<br>SDA, SCL              |                                                                                           | 2.5 to 5.0          |       | 0.2 |       |         |
| Pull-up Resistor Resistance              | R <sub>pu</sub>      | TSENSE1,<br>TSENSE2              |                                                                                           | 2.5 to 5.0          |       | 10  |       | kΩ      |
| Pull-up Resistor Temperature Coefficient | R <sub>puc</sub>     | TSENSE1,<br>TSENSE2              | Ta = −20°C to +70°C                                                                       | 2.5 to 5.0          | −0.05 |     | +0.05 | %/°C    |
| POWER ON RESET                           |                      |                                  |                                                                                           |                     |       |     |       |         |
| Reset Release Voltage                    | V <sub>RR</sub>      | VDD                              |                                                                                           |                     |       |     | 2.4   | V       |
| Initialization Time after Reset release  | T <sub>INIT</sub>    |                                  |                                                                                           | 2.4 to 5.0          |       |     | 90    | ms      |
| TIMER                                    |                      |                                  |                                                                                           |                     |       |     |       |         |
| Time Measurement Accuracy                | T <sub>ME</sub>      |                                  | Ta = 25°C                                                                                 | 2.5 to 5.0          | −1    |     | +1    | %       |
| BATTERY VOLTAGE                          |                      |                                  |                                                                                           |                     |       |     |       |         |
| Voltage Measurement Accuracy             | V <sub>ME</sub> (1)  | VDD                              | Ta = +25°C                                                                                | 4                   | −7.5  |     | +7.5  | mV/cell |
|                                          | V <sub>ME</sub> (2)  |                                  | Ta = −20°C to +70°C                                                                       | 2.5 to 5.0          | −20   |     | +20   |         |
| CURRENT SENSE                            |                      |                                  |                                                                                           |                     |       |     |       |         |
| Input Range                              | V <sub>AMPI</sub>    | SRP, SRN                         |                                                                                           | 2.5 to 5.0          | −24   |     | 24    | mV      |
| Current Measurement Resolution           | I <sub>RES</sub> (1) |                                  | Input range ≤  ±6 mV                                                                      |                     |       | 3   |       | μV      |
|                                          | I <sub>RES</sub> (2) |                                  | ±6 mV  < Input range ≤  ±12 mV                                                            |                     |       | 6   |       |         |
|                                          | I <sub>RES</sub> (3) |                                  | Input range ≥  ±12 mV                                                                     |                     |       | 12  |       |         |

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

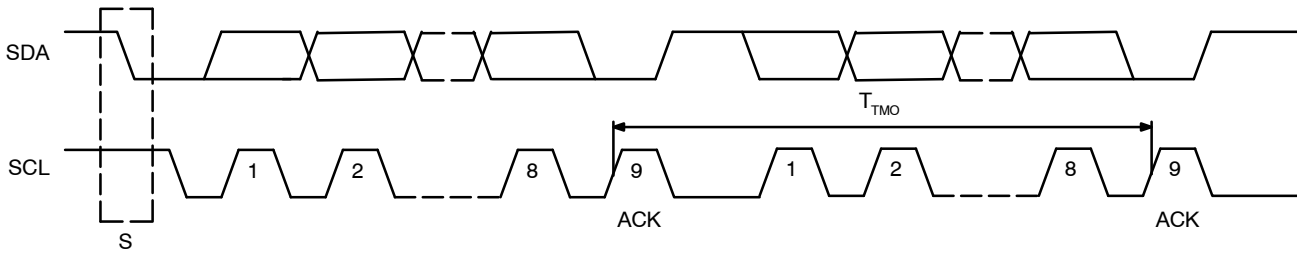
**Table 5. I<sup>2</sup>C SLAVE CHARACTERISTICS** ( $T_A = -40$  to  $+85^\circ\text{C}$ ,  $V_{SS} = 0$  V)

| Parameter                                                                                | Symbol       | Pin/Remarks | Conditions     | $V_{DD}$ (V) | Specification |     | Unit          |
|------------------------------------------------------------------------------------------|--------------|-------------|----------------|--------------|---------------|-----|---------------|
|                                                                                          |              |             |                |              | Min           | Max |               |
| Clock Frequency                                                                          | $T_{SCL}$    | SCL         |                | 2.5 to 5.0   | –             | 400 | kHz           |
| Bus Free Time between STOP Condition and START Condition                                 | $T_{BUF}$    | SCL, SDA    | (See Figure 5) |              | 1.3           | –   | $\mu\text{s}$ |
| Hold Time (repeated) START Condition. First Clock Pulse is Generated after this Interval | $T_{HD:STA}$ | SCL, SDA    | (See Figure 5) |              | 0.6           | –   | $\mu\text{s}$ |
| Repeated START Condition Setup Time                                                      | $T_{SU:STA}$ | SCL, SDA    | (See Figure 5) |              | 0.6           | –   | $\mu\text{s}$ |
| STOP Condition Setup Time                                                                | $T_{SU:STO}$ | SCL, SDA    | (See Figure 5) |              | 0.6           | –   | $\mu\text{s}$ |
| Data Hold Time                                                                           | $T_{HD:DAT}$ | SCL, SDA    | (See Figure 5) |              | 0             | –   | $\mu\text{s}$ |
| Data Setup Time                                                                          | $T_{SU:DAT}$ | SCL, SDA    | (See Figure 5) |              | 100           | –   | ns            |
| Clock Low Period                                                                         | $T_{LOW}$    | SCL         | (See Figure 5) |              | 1.3           | –   | $\mu\text{s}$ |
| Clock High Period                                                                        | $T_{HIGH}$   | SCL         | (See Figure 5) |              | 0.6           | –   | $\mu\text{s}$ |
| Time-out Interval (Notes 1, 2)                                                           | $T_{TMO}$    | SCL, SDA    | (See Figure 6) |              | 12            | 14  | s             |

1. This LSI resets I<sup>2</sup>C communication if the communication takes more than  $T_{TMO}$ . It initializes an internal timer to measure the interval when it detects ninth clock pulse. It can receive a new START condition after the reset.
2. This LSI may lose I<sup>2</sup>C communication at this reset operation. Then if a master can't receive a response it must restart transaction from START condition.



**Figure 5. I<sup>2</sup>C Timing Diagram**



**Figure 6. I<sup>2</sup>C Time-out Interval**

## I<sup>2</sup>C Communication Protocol

Communication protocol type: I<sup>2</sup>C

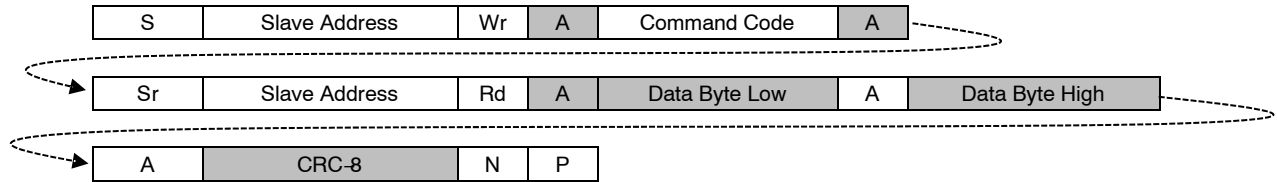
Frequency: Supported up to 400 kHz

Slave Address: 0001011 (The first 8-bits after the Start Condition is 0x16 (WRITE) or 0x17 (READ).)

This LSI will stretch the clock.

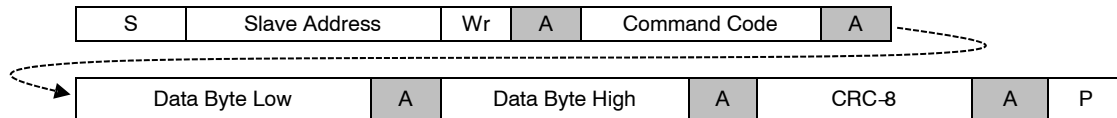
### Bus Protocols

|                                                                                   |   |                                                                                           |
|-----------------------------------------------------------------------------------|---|-------------------------------------------------------------------------------------------|
| S                                                                                 | : | Start Condition                                                                           |
| Sr                                                                                | : | Repeated Start Condition                                                                  |
| Rd                                                                                | : | Read (bit value of 1)                                                                     |
| Wr                                                                                | : | Write (bit value of 0)                                                                    |
| A                                                                                 | : | ACK (bit value of 0)                                                                      |
| N                                                                                 | : | NACK (bit value of 1)                                                                     |
| P                                                                                 | : | Stop Condition                                                                            |
| CRC-8                                                                             | : | Slave Address to Last Data (CRC-8-ATM : ex.3778 mV : 0x16, 0x09, 0x17, 0xC2, 0x0E → 0x86) |
|  | : | Master-to-Slave                                                                           |
|  | : | Slave-to-Master                                                                           |
| ...                                                                               | : | Continuation of protocol                                                                  |



\* When you do not read CRC-8, LSI data is not reliable. CRC-8-ATM ex: (5 bytes) 0x16, 0x09, 0x17, 0xC2, 0x0E → 0x86

**Figure 7. Read Word Protocol**



\* When you do not add CRC-8, the Written data (Data byte Low/High) become invalid. CRC-8-ATM ex: (4 bytes) 0x16, 0x09, 0x55, 0xAA → 0x3B

**Figure 8. Write Word Protocol**

Table 6. FUNCTION OF REGISTERS

| Command Code | Register Name                     | R/W | Range                                                                                                                                        | Unit                                                                                                               | Description                                                       | Initial Value   |
|--------------|-----------------------------------|-----|----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|-----------------|
| 0x00, 0x01   | No Function                       | –   | –                                                                                                                                            | Registers that the access is prohibited.                                                                           |                                                                   | –               |
| 0x03         | TimeToEmpty                       | R   | 0x0000 to 0xFFFF                                                                                                                             | minutes                                                                                                            | Displays estimated time to empty.                                 | 0xFFFF          |
| 0x04         | Before RSOC                       | W   | 0xAA55: 1 <sup>st</sup> sampling<br>0xAA56: 2 <sup>nd</sup> sampling<br>0xAA57: 3 <sup>rd</sup> sampling<br>0xAA58: 4 <sup>th</sup> sampling | Optional Command, especially for obtaining the voltage with intentional timing after power on reset, see Figure 9. |                                                                   | –               |
| 0x05         | TimeToFull                        | R   | 0x0000 to 0xFFFF                                                                                                                             | minutes                                                                                                            | Displays estimated time to full.                                  | 0xFFFF          |
| 0x06         | TSENSE1 Thermistor B              | R/W | 0x0000 to 0xFFFF                                                                                                                             | K                                                                                                                  | Sets B–constant of the TSENSE1 thermistor.                        | 0x0D34 (3380K)  |
| 0x07         | Initial RSOC                      | W   | 0xAA55: Initialize RSOC                                                                                                                      | Initialize RSOC with current voltage when 0xAA55 is set.                                                           |                                                                   | –               |
| 0x08         | Cell Temperature (TSENSE1)        | R   | 0x0980 to 0x0DCC (–30°C to 80°C)                                                                                                             | 0.1K (0.0°C = 0x0AAC)                                                                                              | Displays Cell Temperature.                                        | 0x0BA6 (25°C)   |
|              |                                   | W   |                                                                                                                                              |                                                                                                                    | Sets Cell Temperature in I <sup>2</sup> C mode.                   |                 |
| 0x09         | Cell Voltage                      | R   | 0x09C4 to 0x1388 (2.5 V to 5 V)                                                                                                              | mV                                                                                                                 | Displays Cell Voltage.                                            | –               |
| 0x0A         | Current Direction                 | R/W | 0x0000: Auto mode<br>0x0001: Charge mode<br>0xFFFF: Discharge mode                                                                           | Selects Auto/Charge/Discharge mode.                                                                                |                                                                   | 0x0000          |
| 0x0B         | APA (Adjustment Pack Application) | R/W | 0x0000 to 0xFFFF                                                                                                                             | Sets Adjustment parameter.                                                                                         |                                                                   | –               |
| 0x0C         | APT (Adjustment Pack Thermistor)  | R/W | 0x0000 to 0xFFFF                                                                                                                             | Sets a value to adjust temperature measurement delay timing.                                                       |                                                                   | 0x001E          |
| 0x0D         | RSOC                              | R/W | 0x0000 to 0x0064 (0% to 100%)                                                                                                                | %                                                                                                                  | Displays RSOC value based on a 0–100 scale                        | –               |
| 0x0E         | TSENSE2 Thermistor B              | R/W | 0x0000 to 0xFFFF                                                                                                                             | K                                                                                                                  | Sets B–constant of the TSENSE2 thermistor.                        | 0x0D34 (3380K)  |
| 0x0F         | ITE (Indicator to Empty)          | R   | 0x0000 to 0x03E8 (0.0% to 100.0%)                                                                                                            | 0.1%                                                                                                               | Displays RSOC value based on a 0–1000 scale                       | –               |
| 0x10         | FullChargeCapacity                | R   | 0x0000 to 0xFFFF (0 mAh to 6,553.5 mAh)                                                                                                      | 0.1 mAh                                                                                                            | Displays full charge capacity.                                    | 0x2710 1000 mAh |
| 0x11         | IC Version                        | R   | 0x0000 to 0xFFFF                                                                                                                             | Displays an internal management code.                                                                              |                                                                   | –               |
| 0x12         | Change Of The Parameter           | R/W | 0x0000 to 0x0004                                                                                                                             | Selects a battery profile.                                                                                         |                                                                   | 0x0000          |
| 0x13         | Alarm Low RSOC                    | R/W | 0x0000: Disable<br>0x0001 to 0x0064: Threshold (1% to 100%)                                                                                  | %                                                                                                                  | Sets RSOC threshold to generate Alarm signal.                     | 0x0000          |
| 0x14         | Alarm Low Cell Voltage            | R/W | 0x0000: Disable<br>0x09C4 to 0x1388: Threshold (2.5 V to 5 V)                                                                                | mV                                                                                                                 | Sets Voltage threshold to generate Low Cell Voltage Alarm signal. | 0x0000          |
| 0x15         | IC Power Mode                     | R/W | 0x0001: Operational mode<br>0x0002: Sleep mode                                                                                               | Selects Power mode.                                                                                                |                                                                   | 0x0002          |
| 0x16         | Status Bit                        | R/W | 0x0000 to 0x0003                                                                                                                             | BIT0: Controls TSENSE1 thermistor<br>BIT1: Controls TSENSE2 thermistor                                             |                                                                   | 0x0000          |
| 0x17         | Cycle Count                       | R   | 0x0000 to 0xFFFF                                                                                                                             | count                                                                                                              | Displays cycle count.                                             | 0x0000          |
| 0x18         | DesignCapacity                    | R/W | 0x0190 to 0xFFFF (40 mAh to 6,553.5 mAh)                                                                                                     | 0.1 mAh                                                                                                            | Set a design capacity.                                            | 0x2710 1000 mAh |
| 0x19         | Battery Status                    | R/W | 0x0000 to 0xFFFF                                                                                                                             | Displays various kinds of alarm and estimated state of the battery.                                                |                                                                   | 0x00C0          |



Table 6. FUNCTION OF REGISTERS (continued)

| Command Code | Register Name                      | R/W | Range                                                                   | Unit                     | Description                                                              | Initial Value     |
|--------------|------------------------------------|-----|-------------------------------------------------------------------------|--------------------------|--------------------------------------------------------------------------|-------------------|
| 0x1A         | Number of The Parameter            | R   | 0x0000 to 0xFFFF                                                        |                          | Displays Battery profile code.                                           | –                 |
| 0x1C         | Termination current rate           | R/W | 0x0002 to 0x001E:<br>Threshold<br>(0.02C to 0.3C)                       | 0.01C                    | Sets termination current rate.                                           | 0x0002            |
| 0x1D         | Empty Cell Voltage                 | R/W | 0x0000: Disable<br>0x09C4 to 0x1388:<br>Threshold<br>(2.5 V to 5 V)     | mV                       | Sets empty cell voltage.                                                 | 0x0000            |
| 0x1E         | ITE Offset                         | R/W | 0x0000 to 0x03E8<br>(0.0% to 100.0%)                                    | 0.1%                     | Sets ITE so that RSOC is 0%.                                             | 0x0000            |
| 0x1F         | Alarm High Cell Voltage            | R/W | 0x0000: Disable<br>0x09C4 to 0x1388:<br>Threshold (2.5 V to 5 V)        | mV                       | Sets Voltage threshold to generate High Cell Voltage Alarm signal.       | 0x0000            |
| 0x20         | Alarm Low Temperature              | R/W | 0x0000: Disable<br>0x0980 to 0x0DCC:<br>Threshold (–30°C to 80°C)       | 0.1K<br>(0.0°C = 0x0AAC) | Sets Voltage threshold to generate Low Temperature alarm signal.         | 0x0000            |
| 0x21         | Alarm High Temperature             | R/W | 0x0000: Disable<br>0x0980 to 0x0DCC:<br>Threshold (–30°C to 80°C)       | 0.1K<br>(0.0°C = 0x0AAC) | Sets Voltage threshold to generate High Temperature alarm signal.        | 0x0000            |
| 0x22         | Alarm Over Charging Current        | R/W | 0x0000: Disable<br>0x0001 to 0x7FFF:<br>Threshold<br>(0mV to 32.767mV)  | μV                       | Set Current threshold to generate Over Charging Current alarm signal.    | 0x0000            |
| 0x23         | Alarm Over Discharging Current     | R/W | 0x0000: Disable<br>0x8000 to 0xFFFF:<br>Threshold<br>(–32.768mV to 0mV) | μV                       | Set Current threshold to generate Over Discharging Current alarm signal. | 0x0000            |
| 0x25,0x24    | TotalRuntime                       | R/W | 0x00000000 to 0x00FFFFFF<br>0x24: Lower 16bits<br>0x25: Higher 8bits    | minutes                  | Displays operating time.                                                 | 0x0000            |
| 0x27,0x26    | Accumulated Temperature            | R/W | 0x00000000 to 0xFFFFFFFF<br>0x26: Lower 16bits<br>0x27: Higher 16bits   | 2K<br>minutes            | Displays accumulated temperature.                                        | 0x0000            |
| 0x29,0x28    | Accumulated RSOC                   | R/W | 0x00000000 to 0xFFFFFFFF<br>0x28: Lower 16bits<br>0x29: Higher 16bits   | %<br>minutes             | Displays accumulated RSOC.                                               | 0x0000            |
| 0x2A         | Maximum Cell Voltage               | R/W | 0x09C4 to 0x1388<br>(2.5V to 5V)                                        | mV                       | Displays the maximum historical Cell Voltage.                            | 0x0000            |
| 0x2B         | Minimum Cell Voltage               | R/W | 0x09C4 to 0x1388<br>(2.5V to 5V)                                        | mV                       | Displays the minimum historical Cell Voltage.                            | 0x1388<br>(5V)    |
| 0x2C         | Maximum Cell temperature (TSENSE1) | R/W | 0x0980 to 0x0DCC<br>(–30°C to 80°C)                                     | 0.1K<br>(0.0°C = 0x0AAC) | Displays the historical maximum temperature of TSENSE1.                  | 0x0980<br>(–30°C) |
| 0x2D         | Minimum Cell temperature (TSENSE1) | R/W | 0x0980 to 0x0DCC<br>(–30°C to 80°C)                                     | 0.1K<br>(0.0°C = 0x0AAC) | Displays the historical minimum temperature of TSENSE1.                  | 0x0DCC<br>(80°C)  |
| 0x2E         | Maximum Cell Current               | R/W | 0x0000 to 0x7FFF<br>(0 mV to 32.767 mV)                                 | μV                       | Displays the historical maximum charging current.                        | 0x0000            |
| 0x2F         | Minimum Cell Current               | R/W | 0x8000 to 0x0000<br>(–32.768 mV to 0 mV)                                | μV                       | Displays the historical maximum discharging current.                     | 0x0000            |

**Table 6. FUNCTION OF REGISTERS** (continued)

| Command Code   | Register Name                 | R/W | Range                                                                 | Unit                                     | Description                                            | Initial Value     |
|----------------|-------------------------------|-----|-----------------------------------------------------------------------|------------------------------------------|--------------------------------------------------------|-------------------|
| 0x30           | Ambient Temperature (TSENSE2) | R   | 0x0980 to 0x0DCC<br>(-30°C to 80°C)                                   | 0.1K<br>(0.0°C = 0x0AAC)                 | Displays Ambient Temperature.                          | 0x0BA6<br>(25°C)  |
| 0x31           | Sense resistance              | R/W | 0x000A to 0x07D0<br>(1 mΩ to 200 mΩ)                                  | 0.1 mΩ                                   | Set resistance of a sense resistor.                    | 0x0064<br>(10 mΩ) |
| 0x32           | State of Health               | R   | 0x0000 to 0x0064                                                      | %                                        | Displays State of Health of a battery on a 0–100 scale | 0x0064<br>(100%)  |
| 0x33           | Dynamic Cell current          | R   | 0x8000 to 0x7FFF<br>(-32.768 mV to 32.767 mV)                         | μV                                       | Displays last measured battery current times RSENSE.   | –                 |
| 0x34           | Average Cell current          | R   | 0x8000 to 0x7FFF<br>(-32.768 mV to 32.767 mV)                         | μV                                       | Displays average battery current times RSENSE.         | –                 |
| 0x35           | RemainingCapacity             | R   | 0x0000 to 0xFFFF<br>(0 mAh to 6,553.5 mAh)                            | 0.1 mAh                                  | Displays remaining capacity.                           | –                 |
| 0x37,0x36      | User ID                       | R   | 0x00000000 to 0xFFFFFFFF<br>0x36: Lower 16bits<br>0x37: Higher 16bits | Displays 32bits User ID.                 |                                                        | (Note 3)          |
| More than 0x40 | No function                   | –   | –                                                                     | Registers that the access is prohibited. |                                                        | –                 |

0xFFFF = Hexadecimal notation

3. The initial value of User ID is set on IC at ID Writing process. Please refer to an application note about how to write.

**TimeToEmpty (0x03)**

This register contains estimated time to empty in minutes. The empty is defined as the state that RSOC(0x0D) is 0%.

**Before RSOC (0x04)**

This command is the optional Command, used especially for obtaining the voltage with intentional timing after power on reset. Generally the LSI will get initial RSOC by Open Circuit Voltage (OCV) of a battery. It is desirable for battery current to be less than 0.025C to get expected OCV. (i.e. less than 75 mA for 3000 mAh design capacity battery.) The LSI initializes RSOC by measured battery voltage in initial sequence. But if reported RSOC after reset release is not expected value, “Before RSOC” command or “Initial RSOC” command can initialize RSOC again.

The LSI samples battery voltage four times during initial sequence. The sampling interval is around 10 ms. See Figure 9. RSOC is initialized using the 1st sampled voltage automatically with the initial sequence. The four sampled voltage are maintained until the LSI is reset. “Before RSOC” command can select a voltage for RSOC initialization from them. See Table 7. If the battery is not charged during initial sequence the maximum voltage is suitable for more accurate initial RSOC. Try all “Before RSOC” command and read RSOC (0x0D) to search the maximum voltage. The higher RSOC after the command is caused by the higher voltage.

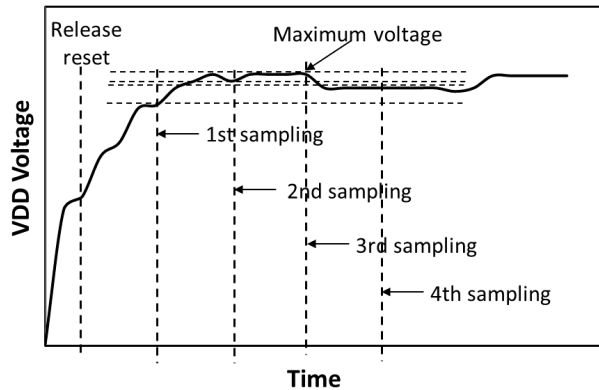


Figure 9. Sampling order for Before RSOC Command

Table 7. BEFORE RSOC COMMAND

| Command Code | DATA   | Sampling order of Battery Voltage for RSOC Initialization |
|--------------|--------|-----------------------------------------------------------|
| 0x04         | 0xAA55 | 1 <sup>st</sup> sampling                                  |
|              | 0xAA56 | 2 <sup>nd</sup> sampling                                  |
|              | 0xAA57 | 3 <sup>rd</sup> sampling                                  |
|              | 0xAA58 | 4 <sup>th</sup> sampling                                  |

**TimeToFull (0x05)**

This register contains estimated time to full in minutes. The full is defined as the state that RSOC (0x0D) is 100%.

**TSENSE1 Thermistor B (0x06)**

Sets B-constant of the thermistor which is connected to TSENSE1. Refer to the specification sheet of the thermistor for the set value to use.

**Initial RSOC (0x07)**

The LSI can be forced to initialize RSOC by sending the Before RSOC Command (0x04 = AA55) or the Initial RSOC Command (0x07 = AA55).

The LSI initializes RSOC by the measured voltage at that time when the Initial RSOC command is written. (See Figure 10). The maximum time to initialize RSOC after the command is written is 1.5 ms.

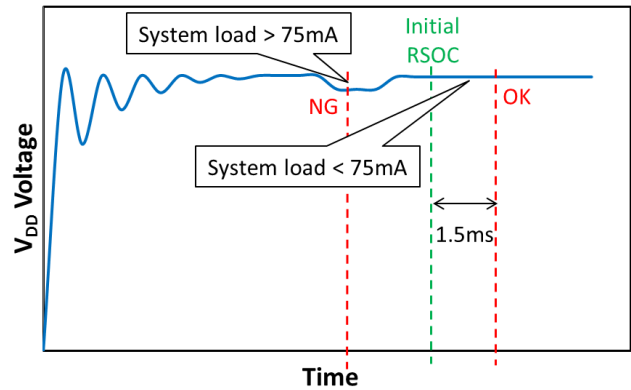


Figure 10. Initial RSOC Command

**Cell Temperature (TSENSE1) (0x08)**

This register contains the cell temperature from  $-30^{\circ}\text{C}$  (0x0980) to  $+80^{\circ}\text{C}$  (0x0DCC) measured in  $0.1^{\circ}\text{C}$  units. When Bit 0 of Status Bit (0x16) is 1 the LSI measures the attached thermistor and loads the temperature into the Cell Temperature register. For this mode, the thermistor shall be connected to the LSI as shown in Figure 1. TSENSE1 pin provides power to the thermistor and senses it. Temperature measurement timing is controlled by the LSI, and the power to the thermistor is supplied only at the time.

The Cell Temperature is used for battery measurement that includes RSOC. Then when Bit 0 of Status Bit (0x16) is 0 the application processor must input temperature of the battery to this register. Update of Cell temperature is recommended if the temperature changes more than  $1^{\circ}\text{C}$  during battery charging and discharging.

**Cell Voltage (0x09)**

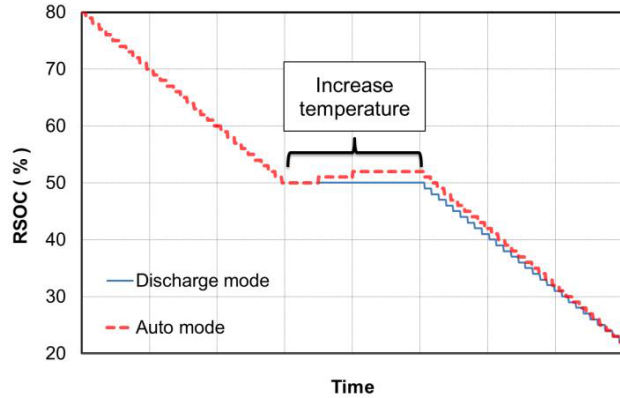
This register contains the  $V_{DD}$  voltage in mV.

### Current Direction (0x0A)

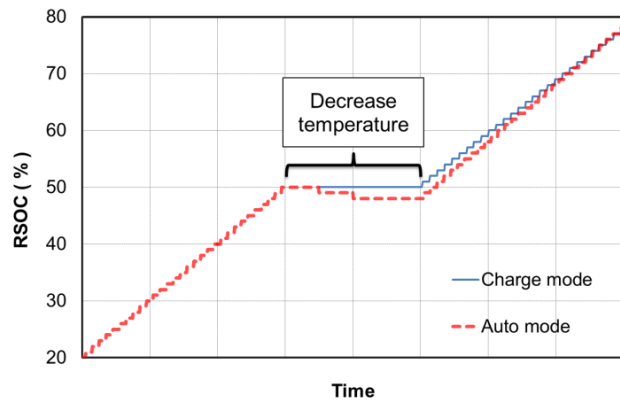
This register is used to control the reporting of RSOC. In Auto mode the RSOC is reported as it increases or decreases. In Charge mode the RSOC is not permitted to decrease. In Discharge mode the RSOC is not permitted to increase.

With consideration of capacity influence by temperature, we recommend operating in Auto because RSOC is affected by the cell temperature. A warm cell has more capacity than a cold cell. Be sure not to charge in the Discharge mode and discharge in the Charge mode; it will create an error.

An example of RSOC reporting is shown in Figure 11 and Figure 12.



**Figure 11. Discharge Mode**  
(An example with increasing in temperature. A warm cell has more capacity than a cold cell. Therefore RSOC increases without charging in Auto mode)



**Figure 12. Charge Mode**  
(An example with decreasing in temperature. A cold cell has less capacity than a warm cell. Therefore RSOC decreases without discharging in Auto mode)

### Adjustment Pack Application (0x0B)

This register contains APA values which are parameter to fit installed battery profiles in a target battery characteristics. Appropriate APA values for the target battery will improve RSOC accuracy.

Typical APA values can be taken from the design capacity of the battery in Table 8. Table 8 shows relations of typical

APA value and the design capacity. Use capacity per 1-cell for the table if some batteries are connected in parallel. Calculate APA values using linear supplement if there is not a requested design capacity in the table. See following formula.

$$\text{APAValue} = \text{Lower\_APA} + (\text{Upper\_APA} - \text{Lower\_APA}) \times \frac{\text{Capacity} - \text{Lower\_Cap.}}{\text{Upper\_Cap.} - \text{Lower\_Cap.}} \quad (\text{eq. 1})$$

Calculation example in case 1500 mAh battery Type-01:

$$\text{APAValue} = 45:0x2D + (50:0x3A - 45:0x2D) \times$$

$$\frac{1500 - 1000}{2000 - 1000} = 52:0x34$$

The upper 8-bits and the lower 8-bits of APA register are for charging and discharging adjustment parameters each. See Table 9. Table 8 shows them as the same value. For example the set value in APA register is 0x0D0D for 0x0D APA value.

But RSOC accuracy may be improved by setting different values each depending on the target battery characteristics.

Please contact ON Semiconductor if you don't satisfy the RSOC accuracy. The deeper adjustment of APA value may improve the accuracy.

**Table 8. TYPICAL APA VALUE FOR CHARGING AND DISCHARGING ADJUSTMENT**

| Design Capacity | APA[15:8], APA[7:0] |            |            |
|-----------------|---------------------|------------|------------|
|                 | Type-01             | Type-06    | Type-07    |
| 50 mAh          | 0x13, 0x13          | 0x0C, 0x0C | 0x03, 0x03 |
| 100 mAh         | 0x15, 0x15          | 0x0E, 0x0E | 0x05, 0x05 |
| 200 mAh         | 0x18, 0x18          | 0x11, 0x11 | 0x07, 0x07 |
| 500 mAh         | 0x21, 0x21          | 0x17, 0x17 | 0x0D, 0x0D |
| 1000 mAh        | 0x2D, 0x2D          | 0x1E, 0x1E | 0x13, 0x13 |
| 2000 mAh        | 0x3A, 0x3A          | 0x28, 0x28 | 0x19, 0x19 |
| 3000 mAh        | 0x3F, 0x3F          | 0x30, 0x30 | 0x1C, 0x1C |
| 4000 mAh        | 0x42, 0x42          | 0x34, 0x34 | –          |
| 5000 mAh        | 0x44, 0x44          | 0x36, 0x36 | –          |
| 6000 mAh        | 0x45, 0x45          | 0x37, 0x37 | –          |

| Design Capacity | APA[15:8], APA[7:0] |            |
|-----------------|---------------------|------------|
|                 | Type-04             | Type-05    |
| 2600 mAh        | 0x10, 0x10          | 0x06, 0x06 |

**Table 9. BIT CONFIGURATION OF APA REGISTER**

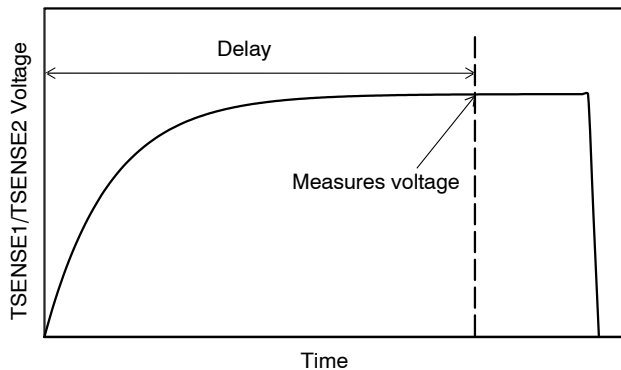
| BITS      | Register Name                        |
|-----------|--------------------------------------|
| APA[15:8] | APA value for charging adjustment    |
| APA[7:0]  | APA value for discharging adjustment |

### Adjustment Pack Thermistor (0x0C)

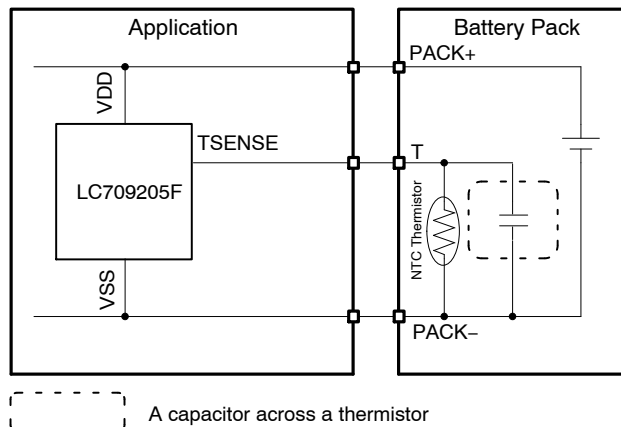
This LSI will power external NTC thermistors periodically to measure CELL and AMBIENT temperature. Internal pull-up resistors of TSENSE1 and TSENSE2 turn on for the charging. This register contains the delay time from the turn-on to the temperature measurement. The delay time is calculated by following formula.

$$\text{Delay} = 0.167 \mu\text{s} \times (200 + \text{APT}) \quad (\text{eq. 2})$$

The both of TSENSE1 and TSENSE2 resistors turn on at the same time. See Figure 13 about the delay and waveform. The default APT (0x001E) will meet most of circuits where a capacitor as shown in Figure 14 is not placed. This will delay the measurement with this register if there is a capacitor in target battery pack.



**Figure 13. Example of TSENSE1 and TSENSE2 Voltage at Temperature Measurement**



**Figure 14. An Example of a Capacitor Across the Thermistor**

### RSOC (0x0D)

This register contains rescaled RSOC in 1%. It is same as ITE (0x0F) when Termination current rate (0x1C) and Empty Cell Voltage (0x1D) are default values.

When this register is written in Operational mode the data may be updated by following two behaviors of the LSI. One is the automatic convergence to close RSOC to actual value of a battery. The other is rescaling. Set Sleep mode to keep

the data. Writing to this register is not necessary in normal operation. ITE (0x0F) will be updated with the writing too.

### TSENSE2 Thermistor B (0x0E)

Sets B-constant of the thermistor which is connected to TSENSE2. Refer to the specification sheet of the thermistor for the set value to use.

### Indicator to Empty (0x0F)

This register contains RSOC in 0.1%.

### FullChargeCapacity (0x10)

This register contains full charge capacity in 0.1 mAh. After battery insertion the initial value is equal to DesignCapacity (0x18). The LSI will learn actual capacity during some charging and discharging cycles and update this register.

### IC Version (0x11)

This register contains an internal management code. The value is not published.

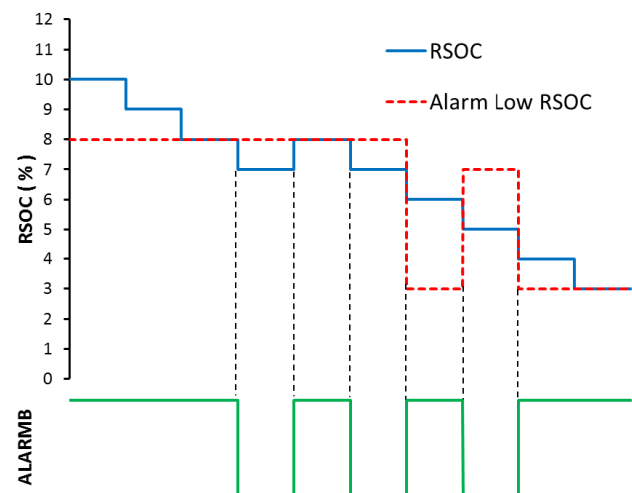
### Change of the Parameter (0x12)

The LSI contains five type battery profiles. This register can select a target battery profile from them. See Table 10. Nominal/rated voltage or charging voltage of the target battery support to determine which battery profile shall be used.

In addition to the selection this command initializes RSOC using the selected battery profile and the 1st sampled voltage during initial sequence. Refer to Before RSOC (0x04) section about the voltage.

### Alarm Low RSOC (0x13)

The ALARMB pin will output low level and the bit 9 of BatteryStatus register (0x19) will be set to 1 when RSOC (0x0D) falls below this value. ALARMB pin will be released from low when RSOC value rises than this value. But the bit 9 keeps 1 until it is written or Power-on reset. Set this register to 0 to disable. Figure 15.



**Figure 15. Alarm Low RSOC**

Table 10. BATTERY PROFILE VS. REGISTER

| IC Type           | Battery Type | Nominal / Rated Voltage | Charging Voltage | Number of the Parameter (0x1A) | Change of the Parameter (0x12) |
|-------------------|--------------|-------------------------|------------------|--------------------------------|--------------------------------|
| LC709205FXE-01TBG | 01           | 3.7 V                   | 4.2 V            | 0x1001                         | 0x00                           |
|                   | 04           | UR18650ZY (Panasonic)   |                  |                                | 0x01                           |
|                   | 05           | ICR18650-26H (SAMSUNG)  |                  |                                | 0x02                           |
|                   | 06           | 3.8 V                   | 4.35 V           |                                | 0x03                           |
|                   | 07           | 3.85V                   | 4.4V             |                                | 0x04                           |

**Alarm Low Cell Voltage (0x14)**

The ALARMB pin will output low level and the bit 11 of BatteryStatus register (0x19) will be set to 1 if Cell Voltage (0x09) falls below this value. ALARMB pin will be released from low if VDD rises than this value. But the bit 11 keeps 1 until it is written or Power-on reset. Set this register to 0 to disable. Figure 16.

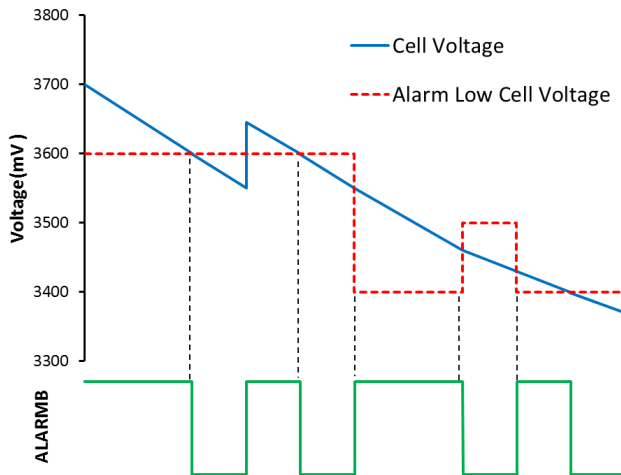


Figure 16. Alarm Low Cell Voltage

**IC Power Mode (0x15)**

The LSI has two power modes. Operational mode (0x15 = 01) or Sleep mode (0x15 = 02). In the Operational mode all functions operate with full calculation and tracking of RSOC during charge and discharge. In the Sleep mode only I<sup>2</sup>C communication functions is enable and ALARMB pin is released from low. When it is switched from Sleep mode to Operational mode RSOC calculation is continued by using the data which was measured in the previous Operational mode.

**Status Bit (0x16)**

This register controls temperature measurement with external thermistors. Bit 0 of this register controls TSENSE1 thermistor and bit 1 controls TSENSE2. When the bits are set to 1 the LSI measures temperature with the attached thermistor and loads the temperature into the Cell Temperature or Ambient Temperature register. When the bits are set to 0 the LSI stops the measurement.

**CycleCount (0x17)**

This register contains the number of charging and discharging cycles of a battery. The cycle is counted as “1” when the total decrement of RSOC reaches 100%. The count is started with 0 after battery insertion. Figure 17.

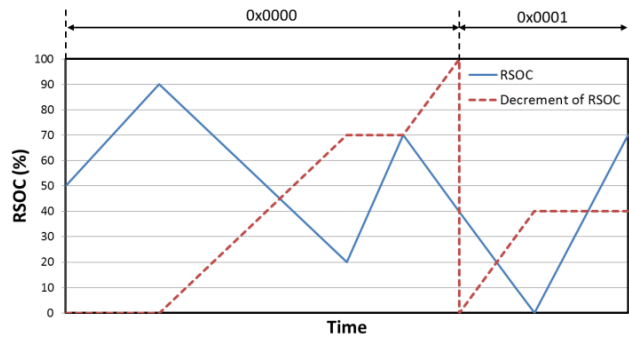


Figure 17. CycleCount

**DesignCapacity (0x18)**

Set design capacity of a target battery in 0.1 mAh. This register is referred to as the initial value of FullChargeCapacity (0x10) and RemainingCapacity (0x35).

**BatteryStatus (0x19)**

This register contains different alarm and estimated states of the battery. See Table 11. Each alarm bit is set to 1 when each alarm condition is satisfied. The bits which are set to 1 once will keep 1 even if the alarm conditions are resolved. Set the alarm bits to 0 after having confirmed the cause of the alarm.

Status bit 6 that is Discharging reports estimated state of the battery. It means that a battery is discharged for 1 and charged for 0.

Status bit 7 that is INITIALIZED helps that an application processor detects the power-on reset of LSI on battery insertion. The bit is set to 1 after power-on reset. Then the processor can detect the power-on reset if it has set the bit to 0 after previous power-on reset.

**Table 11. BATTERY STATUS**

|        | BIT | Function                 | ALARMB control | Initial value |
|--------|-----|--------------------------|----------------|---------------|
| ALARM  | 15  | High Cell Voltage        | ✓              | 0             |
|        | 14  | Reserved                 | –              | 0             |
|        | 13  | Over Charging Current    | ✓              | 0             |
|        | 12  | High Temperature         | ✓              | 0             |
|        | 11  | Low Cell Voltage         | ✓              | 0             |
|        | 10  | Over Discharging Current | ✓              | 0             |
|        | 9   | Low RSOC                 | ✓              | 0             |
|        | 8   | Low Temperature          | ✓              | 0             |
| STATUS | 7   | INITIALIZED              | –              | 1             |
|        | 6   | Discharging              | –              | 1             |
|        | 5   | Reserved                 | –              | 0             |
|        | 4   | Reserved                 | –              | 0             |
|        | 3   | Reserved                 | –              | 0             |
|        | 2   | Reserved                 | –              | 0             |
|        | 1   | Reserved                 | –              | 0             |
|        | 0   | Reserved                 | –              | 0             |

**Number of the Parameter (0x1A)**

The register contains identity of installed battery profile.

**Termination Current Rate (0x1C)**

Set the termination current rate in charging when RSOC (0x0D) arrives at 100% in 0.01C. (i.e. the set value is 0x02 for 3000mAh design capacity and 60mA termination current.) The installed battery profiles are designed so that ITE (0x0F) arrives at 0x3E8 when the battery current rate in charging decreases to 0.02C.

Therefore ITE (0x0F) and RSOC (0x0D) will arrive at the maximum value at the same time when this value is 0x02

(0.02C). The arrival of RSOC to the maximum value becomes early when this value exceeds 0x02. This register produces an offset between ITE and RSOC on full charge side. See Figure 19. This offset value is calculated according to battery profile and this register value.

**Empty Cell Voltage (0x1D)**

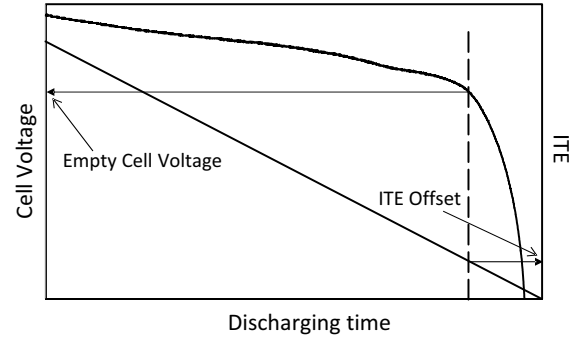
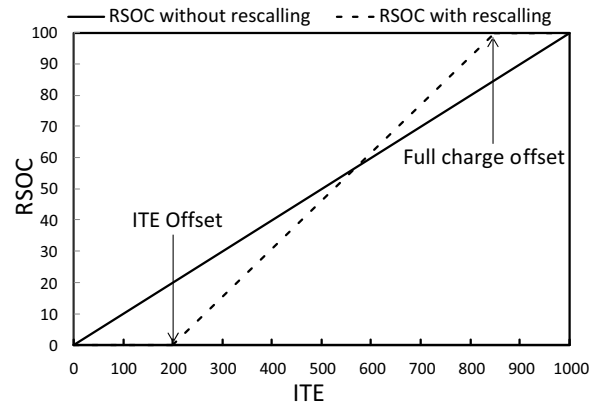
Set the minimum battery voltage when RSOC is 0% in mV. When this LSI detects that Cell Voltage (0x09) is lower than Empty Cell Voltage (0x1D) it will set the ITE (0x0F) value of the moment to ITE Offset (0x1E) automatically. See Figure 18. RSOC (0x0D) is rescaled so that it is 0% when ITE (0x0F) is equal to ITE Offset (0x1E). Following formulas indicate the update conditions of ITE Offset (0x1E).

*Cell Voltage (0x09) < Empty Cell Voltage (0x1D)* (eq. 3)

*ITE (0x0F) > ITE Offset (0x1E)* (eq. 4)

*Cell Temperature (0x08) > 0x0AAC(0 °C)* (eq. 5)

Set this register to 0 not to update ITE Offset (0x1E) automatically.

**Figure 18. Empty Cell Voltage and ITE Offset in Discharging****Figure 19. Rescaled RSOC by ITE Offset and Termination Current Rate**



**ITE Offset (0x1E)**

This register is referred to transform ITE (0x0F) to RSOC (0x0D). RSOC will be rescaled so that it is 0% when ITE (0x0F) is equal to this register. See Figure 19. Refer to Termination current rate section about the Full charge offset in the figure.

There are two methods to update this register. One is to write it directly. The other is an automatic update by Empty Cell Voltage (0x1D). Refer to Empty Cell Voltage section about it.

**Alarm High Cell Voltage (0x1F)**

The ALARMB pin will output low level and the bit 15 of BatteryStatus register (0x19) register will be set to 1 when Cell Voltage (0x09) rises than this value. ALARMB pin will be released from low when Cell Voltage falls below this value. But the bit 15 keeps 1 until it is written or Power-on reset. Set this register to 0 to disable.

**Alarm Low Temperature (0x20)**

The ALARMB pin will output low level and the bit 8 of BatteryStatus register (0x19) will be set to 1 when Cell Temperature (0x08) falls below this value. ALARMB pin will be released from low when Cell Temperature rises than this value. But the bit 8 keeps 1 until it is written or Power-on reset. Set this register or Bit 0 of Status Bit (0x16) to 0 to disable.

**Alarm High Temperature (0x21)**

The ALARMB pin will output low level and the bit 12 of BatteryStatus register (0x19) will be set to 1 when Cell Temperature (0x18) rises than this value. ALARMB pin will be released from low when Cell Temperature falls below this value. But the bit 12 keeps 1 until it is written or Power-on reset. Set this register or Bit 0 of Status Bit (0x16) to 0 to disable.

**Alarm Over Charging Current (0x22)**

The ALARMB pin will output low level and the bit 13 of BatteryStatus register (0x19) will be set to 1 when Dynamic Cell current (0x33) rises than this value. ALARMB pin will be released from low when Dynamic Cell current falls below this value. But the bit 13 keeps 1 until it is written or Power-on reset. Set this register to 0 to disable.

**Alarm Over Discharging Current (0x23)**

The ALARMB pin will output low level and the bit 10 of BatteryStatus register (0x19) will be set to 1 when Dynamic Cell current (0x33) falls below this value. ALARMB pin will be released from low when Dynamic Cell current falls below this value. But the bit 10 keeps 1 until it is written or Power-on reset. Set this register to 0 to disable.

**TotalRuntime (0x24, 0x25)**

This register contains an elapsed time of Operational mode after battery insertion in minutes. The LSI stops the

counting when it reaches 0xFFFFFFFF. When this register is written it starts counting from the written value. It doesn't count in Sleep mode.

**Accumulated Temperature (0x26, 0x27)**

In Operational mode this register accumulates Cell Temperature (0x08) value per minute. It stops the accumulating when it reaches 0xFFFFFFFF. When this register is written it starts accumulating from the written value. It doesn't count in Sleep mode.

**Accumulated RSOC (0x28, 0x29)**

In Operational mode this register accumulates RSOC (0x0D) value per minute. It stops the accumulating when it reaches 0xFFFFFFFF. When this register is written it starts accumulating from the written value. It doesn't count in Sleep mode.

**Maximum Cell Voltage (0x2A)**

The maximum Cell Voltage (0x09) is stored. This register will be updated whenever the higher voltage is detected. If the lower voltage is written it can detect the higher voltage than the written voltage again.

**Minimum Cell Voltage (0x2B)**

The minimum Cell Voltage (0x09) is stored. This register will be updated whenever the lower voltage is detected. If the higher voltage is written it can detect the lower voltage than the written voltage again.

**Maximum Cell Temperature (TSENSE1) (0x2C)**

The maximum Cell Temperature (0x08) is stored. This register will be updated whenever the higher temperature is detected. If the lower temperature is written it can detect the higher temperature than the written temperature again.

**Minimum Cell Temperature (TSENSE1) (0x2D)**

The minimum Cell Temperature (0x08) is stored. This register will be updated whenever the lower temperature is detected. If the higher temperature is written it can detect the lower temperature than the written temperature again.

**Maximum Cell Current (0x2E)**

The maximum Dynamic Cell current (0x33) is stored. It is the maximum charging current. This register will be updated whenever the higher current is detected. If the lower current is written it can detect the higher current than the written current again.

**Minimum Cell Current (0x2F)**

The minimum Dynamic Cell current (0x33) is stored. It is the maximum discharging current. This register will be updated whenever the lower current is detected. If the higher current is written it can detect the lower current than the written current again.



**Ambient Temperature (TSENSE2) (0x30)**

This register contains the ambient temperature from  $-30^{\circ}\text{C}$  (0x0980) to  $+80^{\circ}\text{C}$  (0x0DCC) measured in  $0.1^{\circ}\text{C}$  units. When Bit 1 of Status Bit (0x16) is 1 the LSI measures the attached thermistor and loads the temperature into the Ambient Temperature register. The operation is the same as TSENSE1.

Ambient Temperature is not used for battery gauging. Therefore a temperature measurement of any place is possible.

**Sense Resistance (0x31)**

Set a resistance value of Sense resistor between SRP and SRN in  $0.1\text{m}\Omega$  unit. The range is from  $1\text{m}\Omega$  to  $200\text{m}\Omega$ . The resistance value should be selected to satisfy a maximum battery current and a current resolution requirements. The maximum battery current: IMAX and the resistance: RSENSE must satisfy following formula. Table 12 shows examples of Sense resistance.

$$-24\text{ mV} < \text{IMAX} \times \text{RSENSE} < 24\text{ mV} \quad (\text{eq. 6.})$$

This register is used to measure battery capacity and State of health. Set it in starting flow. See Figure 22 and 23.

**Table 12. EXAMPLES OF SENSE RESISTANCE**

| RSENSE | 0x31 Register | Current Resolution | Current Range |
|--------|---------------|--------------------|---------------|
| 2 mΩ   | 0x0014        | 1500 μA            | ±12 A         |
| 5 mΩ   | 0x0032        | 600 μA             | ±4.8 A        |
| 10 mΩ  | 0x0064        | 300 μA             | ±2.4 A        |
| 20 mΩ  | 0x00C8        | 150 μA             | ±1.2 A        |
| 50 mΩ  | 0x01F4        | 60 μA              | ±0.48 A       |
| 100 mΩ | 0x03E8        | 30 μA              | ±0.24 A       |
| 200 mΩ | 0x07D0        | 15 μA              | ±0.12 A       |

**State of Health (0x32)**

This register contains State of Health of a battery in 1% unit. After the battery insertion, this register is started at 100%. It decreases by deterioration of the battery.

**Dynamic Cell Current (0x33)**

This register contains the latest measured voltage between SRP and SRN in μV. It is signed int. The positive sign indicates battery charging. And the negative sign indicates battery discharging. It is converted to Cell current by dividing by sense resistance.

**Average Cell Current (0x34)**

This register contains the averaged Dynamic Cell current (0x33) in μV.

**RemainingCapacity (0x35)**

This register contains Remaining capacity in 0.1 mAh. The capacity is calculated by FullChargeCapacity (0x10) and ITE (0x0F).

**User ID (0x36, 0x37)**

This register contains 32bits data written in built-in NVM. It is usable for various purposes. Refer to an application note about how to write the NVM.

**HG-CVR2****Hybrid Gauging by Current-Voltage Tracking with Internal Resistance**

**HG-CVR2** is ON Semiconductor's unique method which is used to calculate accurate RSOC. **HG-CVR2** first measures battery voltage and temperature. Precise reference voltage is essential for accurate voltage measurement. LC709205F has accurate internal reference voltage circuit with little temperature dependency.

It also uses the measured battery voltage and internal impedance and Open Circuit Voltage (OCV) of a battery for the current measurement. OCV is battery voltage without load current. The measured battery voltage is separated into OCV and varied voltage by load current. The varied voltage is the product of load current and internal impedance. Then the current is determined by the following formulas.

$$V(\text{VARIED}) = V(\text{MEASURED}) - \text{OCV} \quad (\text{eq. 7.})$$

$$I = \frac{V(\text{VARIED})}{R(\text{INTERNAL})} \quad (\text{eq. 8.})$$

Where  $V(\text{VARIED})$  is varied voltage by load current,  $V(\text{MEASURED})$  is measured voltage,  $R(\text{INTERNAL})$  is internal impedance of a battery. Detailed information about the internal impedance and OCV is installed in the LSI. The internal impedance is affected by remaining capacity, load-current, temperature, and more. Then the LSI has the information as look up table. **HG-CVR2** accumulates battery coulomb using the information of the current and a steady period by a high accuracy internal timer. The remaining capacity of a battery is calculated with the accumulated coulomb.

### How to Identify Aging

By repeating discharge/charge, internal impedance of a battery will gradually increase, and the Full Charge Capacity (FCC) will decrease. In coulomb counting method RSOC is generally calculated using the FCC and the Remaining Capacity (RM).

$$RSOC = \frac{RM}{FCC} \times 100\% \quad (\text{eq. 9.})$$

Then the decreased FCC must be preliminarily measured with learning cycle. But **HG-CVR2** can measure the RSOC of deteriorated battery without learning cycle. The internal battery impedance that **HG-CVR2** uses to calculate the current correlates highly with FCC. The correlation is based on battery chemistry. The RSOC that this LSI reports using the correlation is not affected by aging.

### Automatic Convergence of the Error

A problem of coulomb counting method is the fact that the error is accumulated over time – This error must be corrected. The general gauges using coulomb counting method must find an opportunity to correct it.

This LSI with **HG-CVR2** has the feature that the error of RSOC converges autonomously, and doesn't require calibration opportunities. The error constantly converges in the value estimated from the Open Circuit Voltage. Figure 20 shows the convergent characteristic example from the initialize error.

Also, coulomb counting method cannot detect accurate residual change because the amount of the current from self-discharge is too small but **HG-CVR2** is capable to deal with such detection by using the voltage information.

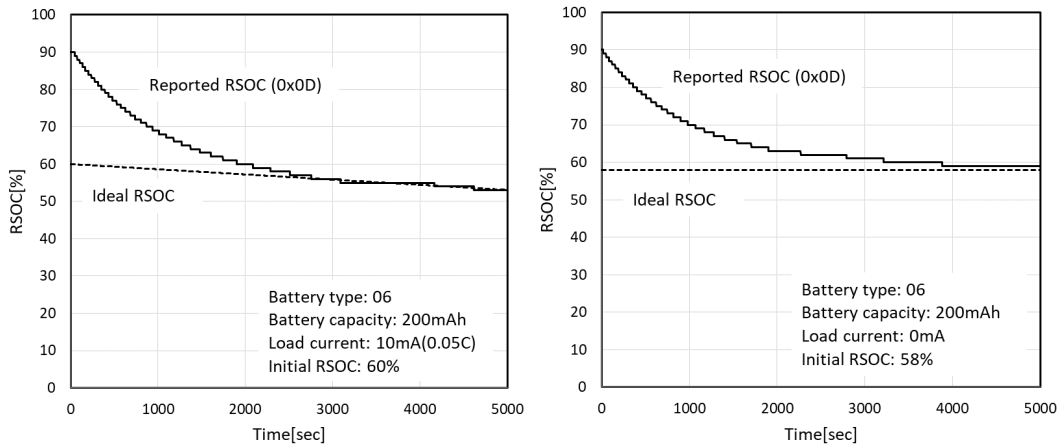
### Simple and Quick Setup

In general, it is necessary to obtain multiple parameters for a fuel gauge and it takes a lot of resource and additional development time of the users. One of the unique features of LC709205F is very small number of parameters to be prepared by the beginning of battery measurement – the minimum amount of parameter which users may make is one because Adjustment pack application register has to have one. Such simple and quick start-up is realized by having multiple profile data in the LSI to support various types of batteries. Please contact your local sales office to learn more information on how to measure a battery that cannot use already-prepared profile data.

### Low Power Consumption

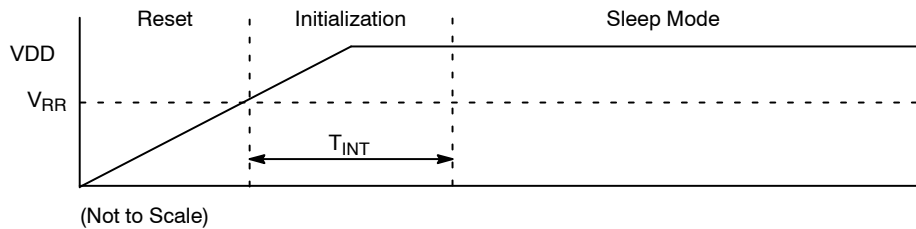
Low power consumption of 2.0 μA is realized in the Operation mode. This LSI monitors charge/discharge condition of a battery and changes the sampling rate according to its change of current. Power consumption reduction without deteriorating its RSOC accuracy was enabled by utilizing this method.

## TYPICAL CHARACTERISTICS



NOTE: This Graph is the example for starting point 90% (includes 30–32% error).

**Figure 20. Convergent Characteristic from the Initialize Error**



**Figure 21. Power On Timing Diagram**

#### Power-on Reset/Battery Insertion Detection

When this LSI detects battery insertion, it is reset automatically. Once the battery voltage exceeds over the  $V_{RR}$ , it will release RESET status and will complete LSI initialization within  $T_{INT}$  to enter into Sleep mode. All registers are initialized after Power-on reset. Then I<sup>2</sup>C communication can be started. Figure 21.

#### Measurement Starting Flow

After the initialization users can start battery measurement by writing appropriate value into the registers by following the flow shown in Figure 22–23. Figure 22 shows Thermistor mode that the LSI measures battery temperature with thermistors. Figure 23 shows I<sup>2</sup>C mode

that the LSI receives battery temperature from an application processor. In the figure Mandatory settings to measure RSOC are enclosed in solid line. Optional settings to use each required function are enclosed in dotted line.

Set some mandatory or optional parameters at the beginning. RSOC (0x0D) is updated to the value corresponding to a selected battery profile after Change of the Parameter command (0x12). Then set the LSI to Operational mode. At the end of starting flow set INITIALIZED bit to 0. An application processor can detect whether the LSI was reinitialized by reading the bit. (For example, for turn-off by Lib-protection IC) Repeat this starting flow again if this bit is changed to 1.

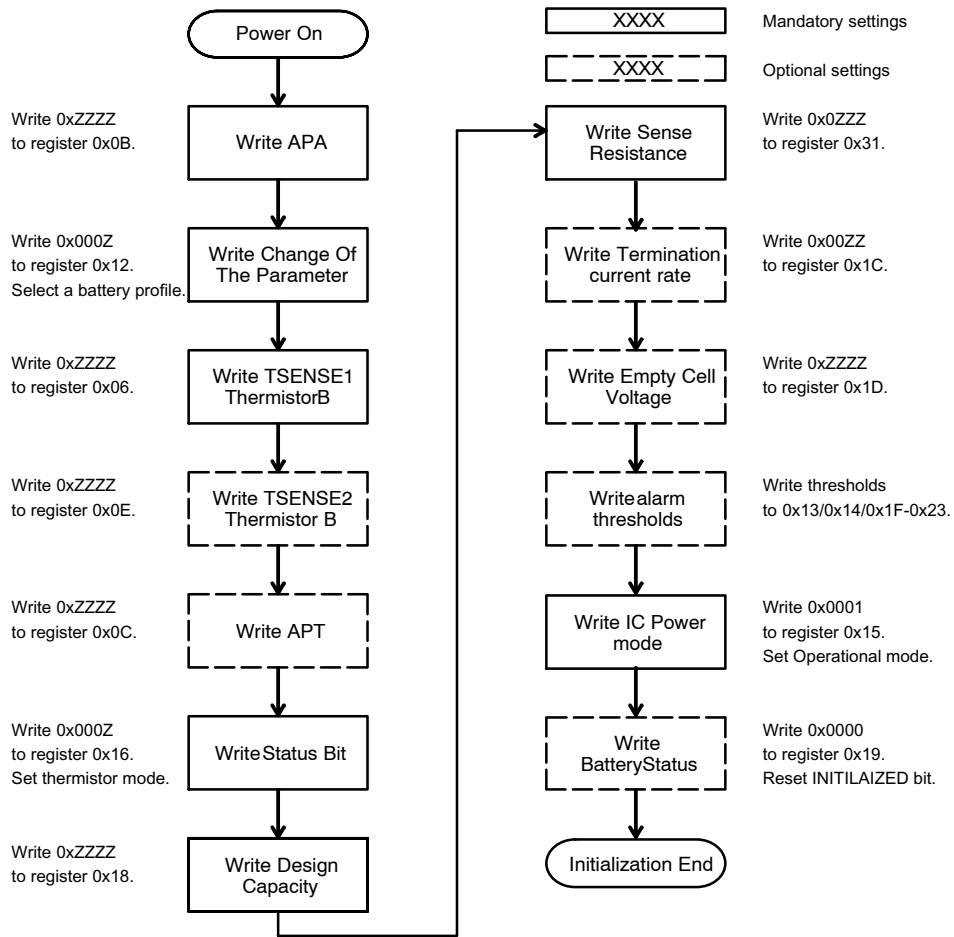


Figure 22. Starting Flow at Thermistor Mode

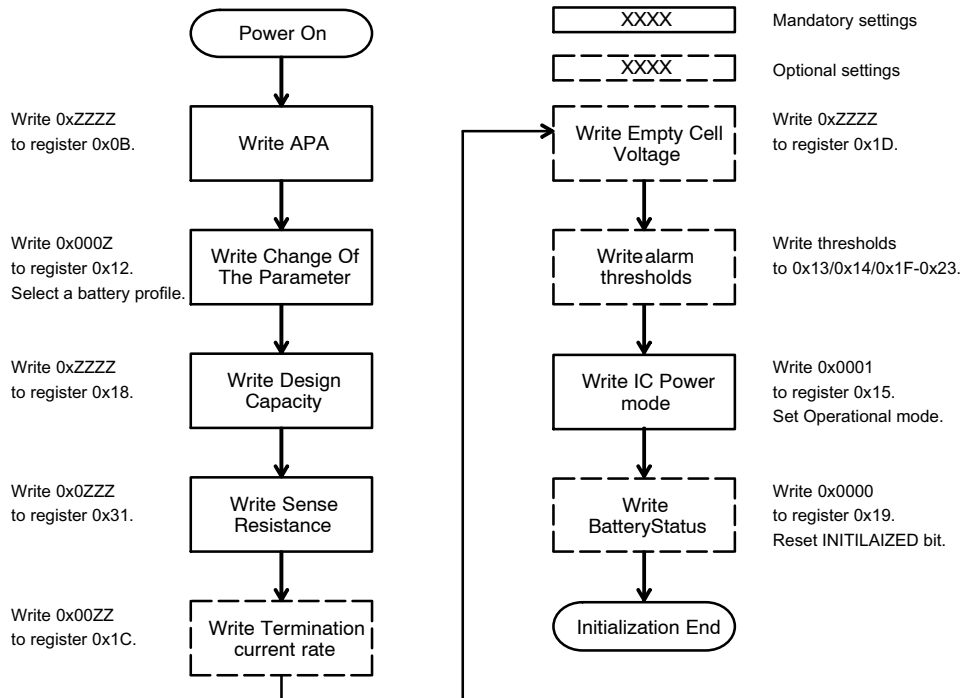


Figure 23. Starting Flow at I²C Mode

## LC709205F

### Layout Guide

Figure 24 shows the recommended layout pattern around LC709205F. Place CVDD and CREG capacitor near the LSI. SRP and SRN should be wired from the inside of the sense resistor footprint.

Figure 25 shows the position to place the LSI on the Power paths. The resistance of the Power paths between Battery or Battery Pack and the LSI affects the gauging. Place the LSI to minimize the resistance. But the resistance of the paths which is connected to only the LSI doesn't affect it.

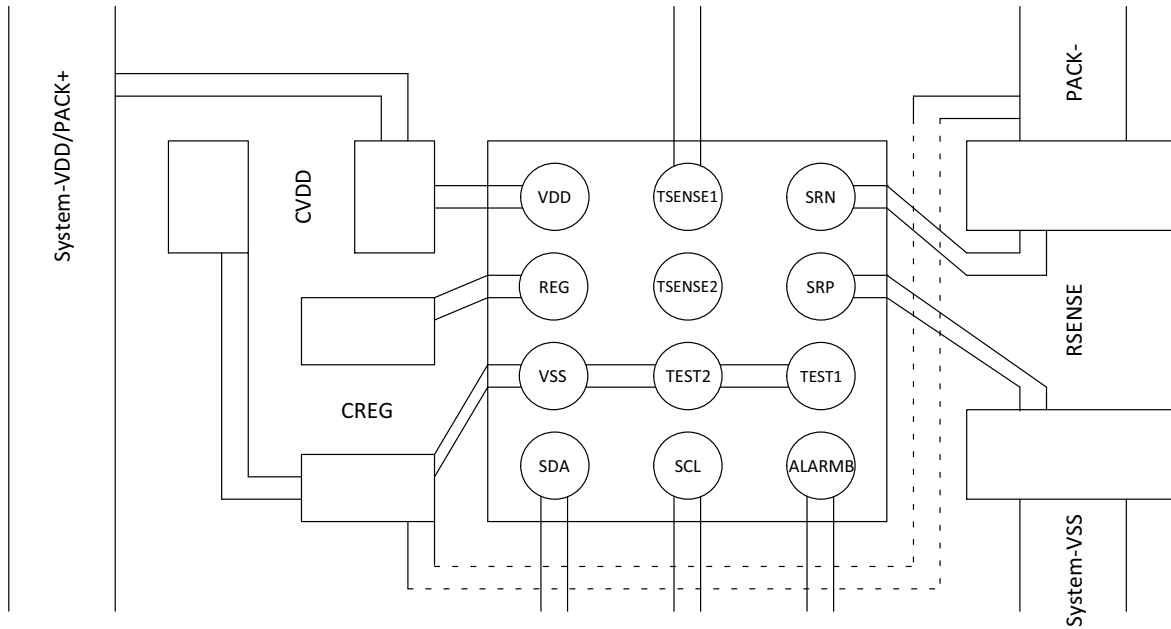


Figure 24. Layout Pattern Example Around LC709205F (Top View)

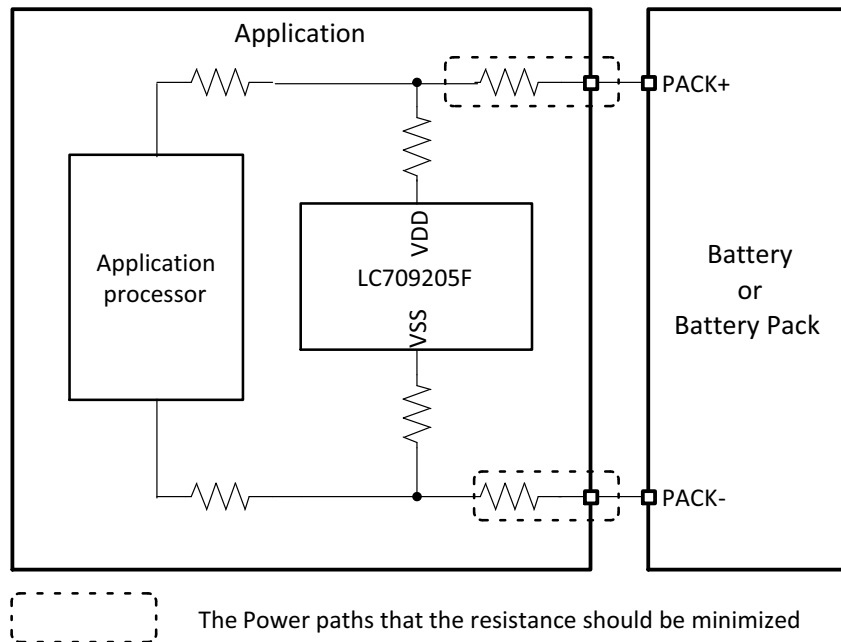


Figure 25. Position to Connect LC709205F on Power Supply Lines

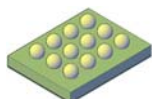
## LC709205F

**Table 13. ORDERING INFORMATION**

| Device            | Package                                             | Shipping <sup>†</sup> |
|-------------------|-----------------------------------------------------|-----------------------|
| LC709205FXE-01TBG | WLCSP12, 1.48x1.91x0.51<br>(Pb-Free / Halogen Free) | 5,000 / Tape & Reel   |

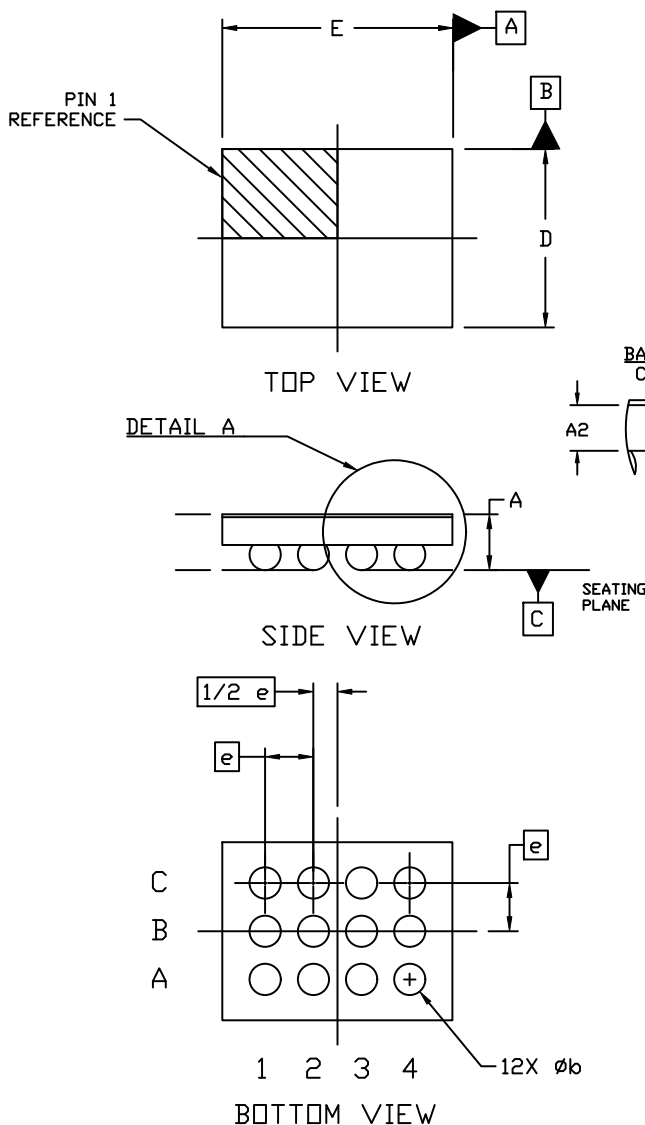
<sup>†</sup>For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, [BRD8011/D](#).

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**WLCSP12, 1.48x1.91x0.51**  
CASE 567XE  
ISSUE A

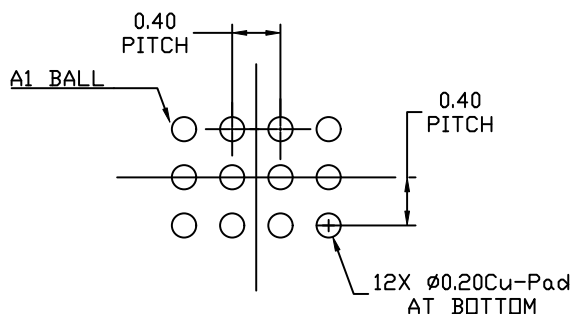
DATE 22 FEB 2019



### NOTES:

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 2009.
2. CONTROLLING DIMENSION: MILLIMETERS
3. DATUM C, THE SEATING PLANE, IS DEFINED BY THE SPHERICAL CROWNS OF THE CONTACT BALLS.
4. COPLANARITY APPLIES TO THE SPHERICAL CROWNS OF THE CONTACT BALLS.
5. DIMENSION b IS MEASURED AT THE MAXIMUM CONTACT BALL DIAMETER PARALLEL TO DATUM C.

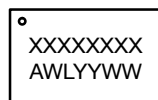
| DIM | MILLIMETERS |      |       |
|-----|-------------|------|-------|
|     | MIN.        | NOM. | MAX.  |
| A   | ---         | ---  | 0.510 |
| A1  | 0.18        | 0.21 | 0.24  |
| A2  | 0.245 REF   |      |       |
| A3  | 0.025 REF   |      |       |
| b   | 0.21        | 0.26 | 0.31  |
| D   | 1.43        | 1.48 | 1.53  |
| E   | 1.86        | 1.91 | 1.96  |
| e   | 0.40 BSC    |      |       |



### RECOMMENDED MOUNTING FOOTPRINT\* (NSMD PAD TYPE)

\* For additional information on our Pb-Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

### GENERIC MARKING DIAGRAM\*



XXXX = Specific Device Code  
A = Assembly Location  
WL = Wafer Lot  
YY = Year  
WW = Work Week

\*This information is generic. Please refer to device data sheet for actual part marking. Pb-Free indicator, "G" or microdot "•", may or may not be present. Some products may not follow the Generic Marking.

|                         |                                |                                                                                                                                                                                  |
|-------------------------|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
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